

## FREE VIBRATIONAL ANALYSIS OF MAGNETO-RHEOLOGICAL AIRCRAFT RIB STRUCTURE

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### ABSTRACT

*The concept of vibration mitigation with smart fluids within flexible structures has attracted researcher's interest in the past two decades. A large amount of research work has been done on the structures with electro rheological fluids, but there has been a little work with the magneto rheological fluids. The objective of this research paper is to increase the mechanical vibration absorbing properties of the Magneto Rheological aircraft rib structure as a direct result of increasing its damping ratio via an increased stiffness. This is achieved through the implementation of the magnetic field upon the periphery of the proposed model structure under the influence of magnetic flux generated by 100 neodymium magnets, each of which generates a magnetic field intensity of 0.075 Tesla. Upon calculation of the damping ratio of all the entities involved, it was found that in the case of cross beam rib structure the damping ratio saw an increase of 44% and in case of vertical beam structure, the damping ratio saw an increase of 13.7%.*

**KEYWORDS:** MR Fluid, Aircraft Rib Structure, Free Vibration Analysis, Damping, Magnetic Field & Permanent Magnets

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### 1. INTRODUCTION

Magneto Rheological Fluid (MRF) is colloidal suspension whose rheological properties (e.g., Viscosity) can be controlled under the influence of external magnetic field and metal particles. These fluids are suitable especially in areas where controlled fluid motion is required since they improve the performance of a system by transmitting force in a controlled manner with the help of magnetic field [1]. It is a free-flowing liquid state in the absence of a magnetic field while its viscosity increases on an application of magnetic field [2]. A magneto rheological fluid comprising a magnetizable particle component and a carrier component [3].

An increasing number of industrial applications show how the MR fluids peculiar properties may be used to provide performance optimization in semi-active damping and dissipative devices [4]. MR dampers have attracted significant attention in structural control applications [5]. Seismic response reduction using MR dampers is an area of research that has received large attention recently [6]. Lately, large-scale MR fluid dampers have been considered for structural vibration mitigation.

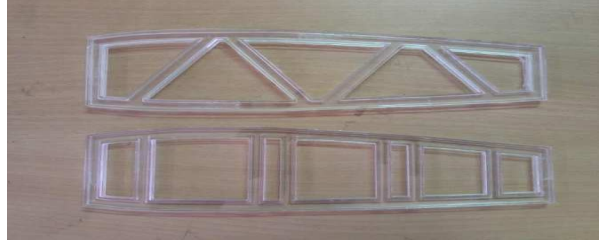
### 2. METHODOLOGY

In this paper, an experimental approach to study the vibrations of MR fluid-filled aircraft ribs were described. Two different configurations of ribs were taken and tested. The stiffness and damping characteristics of the ribs with and without MR fluid were investigated for a specified magnetic field. The ribs were tested in free

vibration condition in a setup that included accelerometer and data acquisition through LabVIEW.

### ToolsUsed

**Acrylic Resin:**Acrylic resins are substances derived from acrylic acid, methacrylic acid or other related compounds and they are group related to thermoplastic or thermosetting plastic. This resin was used to fabricate the rib structure.



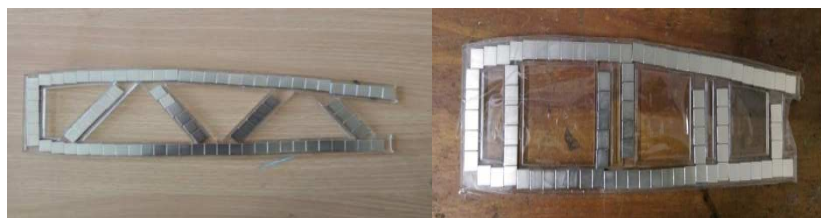
**Figure 1: Aircraft Rib Constructed from Acrylic Resin (Cross Beam and Vertical Beam Rib Structure)**

**Magneto Rheological Fluid:**MRF 132DG supplied by the Lord Corporation was used as anMR fluid, theseare oils that are filled with iron particles. Magneto-Rheological (MR) fluids can respond quickly, precisely and proportionally for controllable energy-dissipation when subjected to varying levels of a magnetic field [7]. MR fluid was injected in the rib configurations and sealed using chloroform.



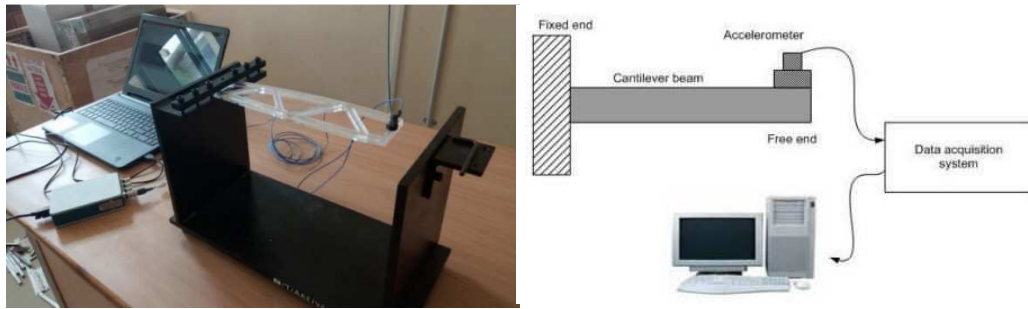
**Figure 2: MR Fluid Filled Ribs**

**Neodymium Rare Earth Magnets:**Neodymium rare earth magnets( $\text{Nd}_2\text{Fe}_{14}\text{B}$ ) are strong permanent magnets with magnetic field greater than 1.4 Tesla. 70 Magnets with 1 square cm dimension were arranged in aircraft rib that served as a source of a magnetic field in the experiment.



**Figure3: Neodymium Earth Magnets Arranged in the Rib**

### Experimental Set Up for Free Vibration of a Cantilever Beam



**Figure4: Cantilever Beam Setup with Accelerometer Mounted on the Top of the Rib Structure**

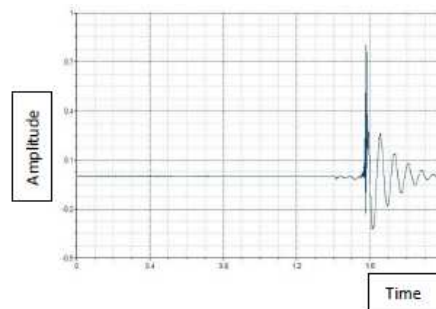
By providing free vibration to the beam with a sine wave, the acrylic beam oscillates with simple harmonic motion. When the beam is left to vibrate freely, without applying external forces, the beam will vibrate at its own frequency called natural frequency. Since the system loses its energy with time, its amplitude of the response also decreases with time. The rate at which this amplitude decreases is known as the logarithmic decrement.

## RESULTS & DISCUSSIONS

### Without MR Fluid

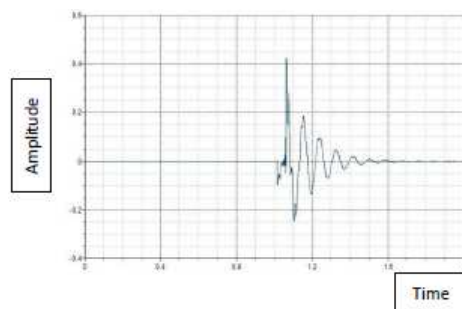
The first set of experiment is done without the implementation of MR Fluid. In this case, an offset of the aircraft rib structure is prepared as the model to fill in the void space. The noticeable fact is that the sinusoidal waveform represents the dying down of the amplitude in due time after the waveform is generated. In layman's terms, the prime objective of the experiment is to reduce the amount of time taken for the wave to move its median to zero.

#### Model 1: (Cross Beam Rib Structure)



**Figure 5: Logarithmic Decrement (Without MR Fluid)**

#### Model 2: (Vertical Beam Rib Structure)



**Figure 6: Logarithmic Decrement (Without MR Fluid)**

The logarithmic decrement is the natural logarithm of the ratio of the amplitude of any two successive peaks: where  $x(t)$  is the amplitude at time  $t$  and  $x(t+nT)$  is the amplitude of the peak  $n$  periods away, where  $n$  is an integer number of successive, positive peaks.

$$\delta = \frac{1}{n} \ln \frac{x(t)}{x(t+nT)}$$

The damping ratio can be found for any two adjacent peaks. This method is used when  $n=1$  and is derived from the general method above:

$$\zeta = \frac{1}{\sqrt{1 + \left(\frac{2\pi}{\ln(x_0/x_1)}\right)^2}},$$

where  $x_0$  and  $x_1$  are any two successive peaks.

This therefore given by:

$$\zeta = \frac{\ln(x_0/x_1)}{2\pi}.$$

### With MR fluid

The graph represents the Logarithmic Decrement or the reduced amplitude of the waveform from the point of origin with respect to time.

#### Model 1: (Cross Beam Rib Structure)

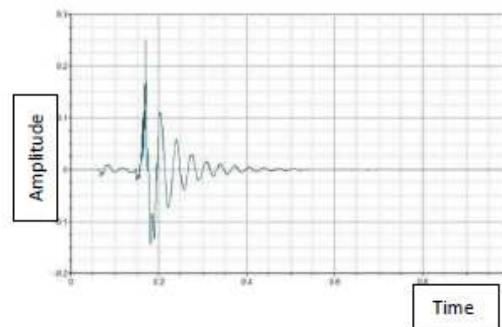


Figure 7: Logarithmic Decrement (with Magnetic Field)

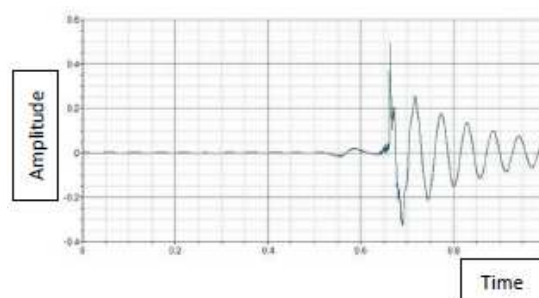
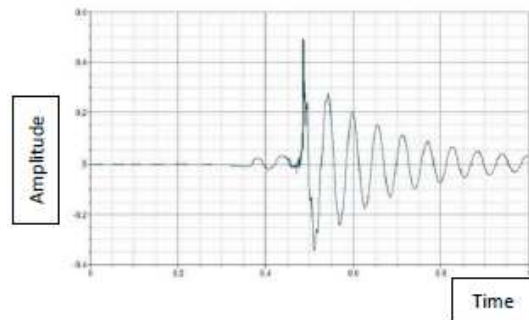
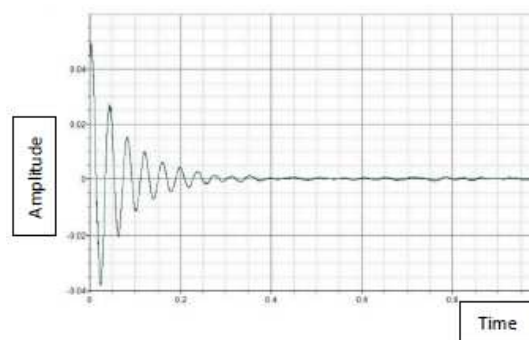


Figure 8: Logarithmic Decrement (Without Magnetic Field)

**Model 2: (Vertical Beam Rib Structure)****Figure 9: Logarithmic Decrement (with Magnetic Field)****Figure 10: Logarithmic Decrement (Without Magnetic Field)****Result Comparison****Table 1: Comparison of Results**

	DAMPING RATIO			
	Configuration 1 (Model 1 Cross Beam)		Configuration 2 (Model 2 Vertical Beam)	
	Without Magnetic Field	With Magnetic Field	Without Magnetic Field	With Magnetic Field
Without MR Fluid	0.0643	----	0.0566	----
With MR Fluid	0.0566	0.093	0.0543	0.0644

As the above table clearly shows, the damping ratio is increased when the MR fluid is activated, and it converts to a semisolid phase. This transformation allows for increased stiffness in each of the models. This relation is showed by the following formula:

$$\zeta = \frac{c}{c_c},$$

$$\zeta = \frac{\text{actual damping}}{\text{critical damping}},$$

where the system's equation of motion is

$$m \frac{d^2 x}{dt^2} + c \frac{dx}{dt} + kx = 0$$

and the corresponding critical damping coefficient is

$$c_c = 2\sqrt{km}$$

or

$$c_c = 2m\omega_n$$

## CONCLUSIONS

For the Cross-beam configuration, the damping ratio without Magneto Rheological fluid gives the value to be 0.063 which is then shot at a higher value when tested for with activated Magneto Rheological Fluid, this value is found to be 0.093 which is a significant increase from a previous value. This proves the objective of this paper that the vibration absorption quality of an entity can be increased by increasing its stiffness via activated MR fluid. Upon calculation of the damping ratio of all the entities involved it is found that in the case of cross beam rib structure the damping ratio saw an increase of 44% and in case of vertical beam structure the damping ratio saw an increase of 13.7%. Therefore, this provides conclusive evidence that we increase the vibration absorbing capabilities of the MR fluid structure by increasing its damping ratio.

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